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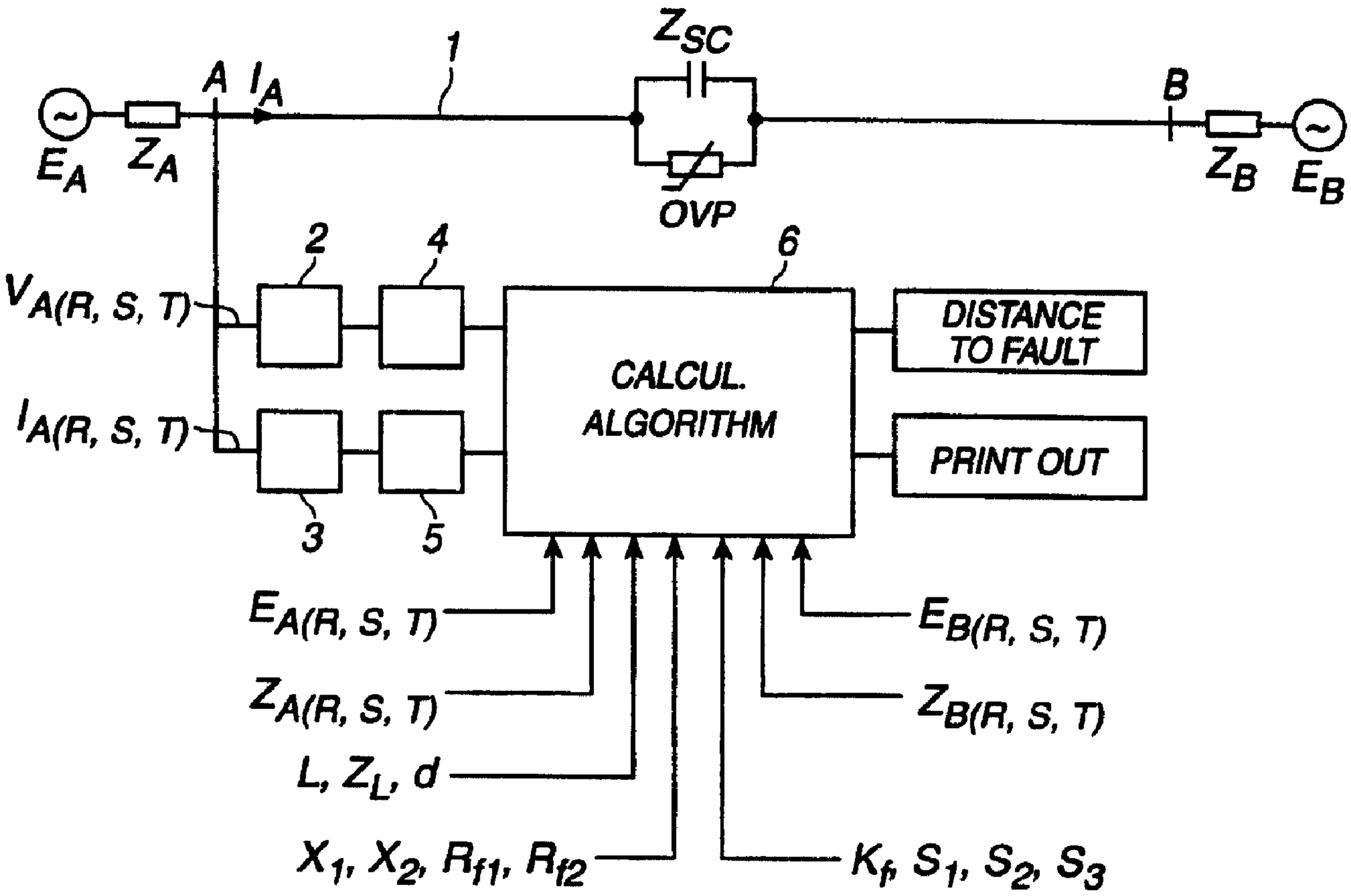
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(57) Abrégé/Abstract:
The present invention relates to a method for locating a fault on a power transmission line which is series-compensated with capacitors. The site of the fault is determined with the aid of measured currents and voltages at one of the two ends of the power

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transmission line before and after the occurrence of the fault and a calculating algorithm based on impedance models of the power transmission line before and after the occurrence of the fault.

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(54) Title: LOCATION OF FAULT ON SERIES-COMPENSATED POWER TRANSMISSION LINES

(57) Abstract

The present invention relates to a method for locating a fault on a power transmission line which is series-compensated with capacitors. The site of the fault is determined with the aid of measured currents and voltages at one of the two ends of the power transmission line before and after the occurrence of the fault and a calculating algorithm based on impedance models of the power transmission line before and after the occurrence of the fault.

Location of fault on series-compensated power transmission lines

TECHNICAL FIELD

The present invention forms an integral part of a protection system for power transmission lines which are series-compensated with capacitors. Specifically, the invention relates to a method and a device for locating a fault which has occurred on the power transmission line. The distance from a station, located at one end of the power transmission line, to the fault is determined with the aid of calculating algorithms based on impedance models of the power transmisssion line and voltages and currents measured at the station before and after the occurrence of the fault.

BACKGROUND ART, PROBLEMS

A method for fault location on a three-phase power transmission line is known from US Patent No. 4,559,491. The method for fault location on a three-phase power transmission line, described in US Patent No. 4,559,491, is based on an impedance model of the power transmission line. A condition for the method according to US Patent No. 4,559,491 is that the power transmission line has a linear impedance also when a fault has occurred. Series capacitors for phase compensation are normally provided with overvoltage protection devices in the form of some protection component with a non-linear characteristic in the area of interference and the method according to US Patent No. 4,559,491 is therefore not applicable to a three-phase power transmission line with series capacitors for phase compensation.

From US Patent No. 4,719,580 it is known that fault location on a three-phase power transmission line may be made according to method based on a waveguide model of

the power transmission line. Fault location on a power transmission line with series capacitors for phase compensation based on a waveguide model of the power transmission line may, for certain types of faults, give a misleading result and this fault-location technique has therefore not been accepted by the users.

A method for fault location based on an impedance model of the power transmission line should take into consideration the fact that the occurrence of a fault on the monitored power transmission line entails the feeding of electric power from both ends of the power transmission line to the site of the fault in question since otherwise the fault location cannot be performed with sufficient accuracy. To obtain a result with satisfactory accuracy in the fault-position determination, fault location based on an impedance model of the power transmission line assumes that the power inputs from the two ends of the power transmission line are determined by measuring or calculating the two power inputs. From US Patent No. 5,455,776 it is known that fault location on a three-phase transmission line may be made with a method which assumes measurement of voltage and current at the two ends of the monitored transmission line. The method could be adapted to series-compensated transmission lines but has the disadvantage of being dependent on measured values from the two ends of the transmission line, which complicates the fault location and makes it more expensive compared with methods operating with measured values from one end of the transmission line only, normally the end of the transmission line where the fault location is arranged.

A method for fault location based on measurement at one end of the transmission line only is described in *IEEE Transaction on Power Apparatus and Systems, Vol. PAS-104, No. 2, February 1985, pp. 424 - 436*. This method assumes that the monitored part of the transmission line is

described by a linear model and the method is thus not useful for series-compensated transmission lines with non-linear protection devices for protecting the capacitors against overvoltage.

SUMMARY OF THE INVENTION

The present invention relates to a method and a device for locating a fault which has occurred on the power transmission line.

According to a first aspect, the invention provides a method for location of a fault, and determination of a resultant fault resistance, which has occurred on a power transmission line which is series-compensated with a capacitor, with a parallel-connected overvoltage protection device, between two stations (A) and (B), wherein the distance to the fault from one station (A) and the fault resistance are determined by means of values measured in said station (A) of voltage before and voltage and current after the occurrence of the fault, characterized in that, if the fault occurred between the series capacitors and station B, the distance to the fault is determined by

$$x_{11} = \frac{\mathrm{Im}(\underline{b}_1) - \sqrt{\mathrm{Im}(\underline{b}_1)\mathrm{Im}(\underline{b}_1) - 4\,\mathrm{Im}(\underline{a}_1)\mathrm{Im}(\underline{c}_1)}}{2\,\mathrm{Im}(\underline{a}_1)} \qquad (14)$$

which is the solution to a first distance-to-fault equation

$$\underline{a}_1 x_1^2 - \underline{b}_1 x_1 + \underline{c}_1 - R_{f1} = 0 \qquad (9)$$

where $\underline{a}_1$, $\underline{b}_1$ and $\underline{c}_1$ designate complex coefficients which, via a first auxiliary vector

$$D_1 = (Z_A + Z_B + Z_L)(I_{A_post} - I_{A_pre}) + Z_{SC_post} I_{A_post} - Z_{SC_pre} I_{A_pre} \qquad (10)$$

and

D_1^T, which designates the transpose matrix of D_1,

may be calculated as follows

$$\underline{a}_1 = \frac{D_1^T}{D_1^T D_1} Z_L K_f Z_L I_{A_post} \qquad (11)$$

$$\underline{b}_1 = \frac{D_1^T}{D_1^T D_1}(Z_L K_f \left[V_{A_post} + \left(Z_L - Z_{SC_post} \right) I_{A_post} \right] + Z_B K_f Z_L I_{A_post}) \qquad (12)$$

$$\underline{c}_1 = \frac{D_1^T}{D_1^T D_1}(Z_L + Z_B)(V_{A_post} - Z_{SC_post} I_{A_post}) K_f \qquad (13)$$

where:

Z_A is equal to a source impedance of a backward power network,

Z_B is equal to a source impedance of a forward power network,

Z_L is equal to an impedance of the power transmission line,

index post identifies a value after the occurrence of a fault,

index pre identifies a value before the occurrence of a fault,

I_A is equal to a fault current,

Z_{SC} is equal to a non-linear impedance,

K_f is equal to a fault-type matrix,

and where $Im(a_1)$, $Im(b_1)$ and $Im(c_1)$ are equal to the imaginary part of the coefficients, and that

the fault resistance becomes equal to

$$R_{f1} = Re(a_1) r_{11}^2 - Re(b_1) r_{11} + Re(c_1) \qquad (15)$$

where $Re(a_1)$, $Re(b_1)$ and $Re(c_1)$ are equal to the real part of the coefficients.

The invention also concerns a method for location of a fault, and determination of a resultant fault resistance, which has occurred on a power transmission line which is series-compensated with a capacitor, with a parallel-connected overvoltage protection device, between two stations (A) and (B), wherein the distance to the fault from one station (A) and the fault resistance are determined by means of values measured in said station (A) of voltage before and voltage and current after the occurrence of the fault, **characterized** in that, if the fault occurred between station A and the series capacitors, the distance to the fault is determined by

$$x_{21} = \frac{\mathrm{Im}(\underline{b}_2) - \sqrt{\mathrm{Im}(\underline{b}_2)\mathrm{Im}(\underline{b}_2) - 4\,\mathrm{Im}(\underline{a}_2)\mathrm{Im}(\underline{c}_2)}}{2\,\mathrm{Im}(\underline{a}_2)} \qquad (23)$$

which is the solution to a second distance-to-fault equation

$$\underline{a}_2 x_2^2 - \underline{b}_2 x_2 + \underline{c}_2 - R_{f2} = 0 \qquad (18)$$

where $\underline{a}_2$, $\underline{b}_2$ och $\underline{c}_2$ designate complex coefficients which, with the aid of a second auxiliary vector

$$\mathbf{D}_2 = (Z_A + Z_B + Z_L)(\mathbf{I}_{A_post} - \mathbf{I}_{A_pre}) + Z_{SC_post}\mathbf{I}_{A_post} - Z_{SC_pre}\mathbf{I}_{A_pre} \qquad (19)$$

and

$\mathbf{D}_2^T$, which designates the transpose matrix of $\mathbf{D}_2$, the coefficients $\underline{a}_2$, $\underline{b}_2$ and $\underline{c}_2$ may be calculated as follows:

$$\underline{a}_2 = \frac{\mathbf{D}_2^I}{\mathbf{D}_2^T\mathbf{D}_2} Z_L K_f Z_L \mathbf{I}_{A_post} \qquad (20)$$

$$\underline{b}_2 = \frac{\mathbf{D}_2^T}{\mathbf{D}_2^T\mathbf{D}_2}(\mathbf{Z}_L\mathbf{K}_f\mathbf{V}_{A_post} + \left[\mathbf{Z}_L + \mathbf{Z}_{SC_post} + \mathbf{Z}_B\right]\mathbf{K}_f\mathbf{Z}_L\mathbf{I}_{A_post}) \quad (21)$$

$$\underline{c}_2 = \frac{\mathbf{D}_2^T}{\mathbf{D}_2^T\mathbf{D}_2}(\mathbf{Z}_L + \mathbf{Z}_B + \mathbf{Z}_{SC_post})\mathbf{K}_f\mathbf{V}_{A_post} \quad (22)$$

where:

Z_A is equal to a source impedance of a backward power network,

Z_B is equal to a source impedance of a forward power network,

Z_L is equal to an impedance of the power transmission line,

index post identifies a value after the occurrence of a fault,

index pre identifies a value before the occurrence of a fault,

I_A is equal to a fault current,

Z_{SC} is equal to a non-linear impedance,

K_f is equal to a fault-type matrix,

and where $Im(a_2)$, $Im(b_2)$ and $Im(c_2)$ are equal to the imaginary part of the coefficients, and that

the fault resistance becomes

$$R_{f2} = \mathrm{Re}(a_2)v_{21}^2 - \mathrm{Re}(b_2)v_{21} + \mathrm{Re}(c_2) \quad (24)$$

where $Re(a_2)$, $Re(b_2)$ and $Re(c_2)$ are equal to the real part of the coefficients.

In another aspect, the present invention provides a method for determining which of a located fault as defined above represents the true location, characterized in that, if the located fault is a three-phase fault, it is asked whether R_{f1} is greater than R_{f2}, and if the answer is yes, it is assumed, as a first assumption, that the fault is an R_{f2} fault, and it is asked whether $R_{f2} > R_0$

where R_0 is a preset minimum value, and if the answer is yes, the distance to fault is x_{21}, and if the answer is no, the distance to fault is x_{11}

and that if R_{f1} is smaller than R_{f2}, it is assumed, as a first assumption, that the fault is an R_{f1} fault, and it is asked whether $R_{f1} > R_0$ and if the answer is yes, the distance to fault is x_1, and if the answer is no, the distance to fault is x_2

if the located fault is an unsymmetrical fault, the phase currents through the fault resistance are first determined for a fault according to claim 1 according to

$$i_{E(R,S,T1)} = i_{A(R,S,T)} + i_{B(R,S,T1)} \qquad (25)$$

where

$i_{A(R,S,T)}$ are the phase currents measured in station A

$i_{B(R,S,T1)}$ is determined by means of equation (2) ($i_B = I_{B\text{-}post}$)

and for a fault according to claim 2 according to

$$i_{E(R,S,T2)} = = i_{A(R,S,T)} + i_{B(R,S,T2)} \qquad (26)$$

where

$i_{B(R,S,T2)}$ is determined by means of equation (3) ($i_B = I_{B\text{-}post}$)

whereupon it is asked

whether i_{f1} is greater than i_{f2}, and if the answer is yes, it is assumed, as a first assumption, that the fault is an R_{f2} fault, and it is asked whether $R_{f2} > R_0$ where R_0 is a preset minimum value, and if the answer is yes, the distance to fault is x_{21}, and if the answer is no, the distance to fault is x_{11}

and if i_{f1} is smaller than i_{f2}, it is assumed, as a first assumption, that the fault is an R_{f1} fault, and it is asked

whether $R_{f1} > R_0$, and if the answer is yes, the distance to fault is x_1, and if the answer is no, the distance to fault is x_2.

In a further aspect, the invention concerns a device for carrying out the method for location of a fault, and determination of a resultant fault resistance, which has occurred on a series-compensated power transmission line between two stations A and B as described above, characterized in that the device comprises measuring device for continuous measurement of phase currents and phase voltages in one of the station (A), measurement converters for filtering and storage of a number of these consecutively measured values, a calculating unit which is provided with the calculating algorithms included in the method, including iteration possibilities, and which is arranged for receiving signals in the form of the measured, filtered and stored pre-fault phase currents and phase voltages as well as measured and filtered values of post-fault phase currents and phase voltages as well as signals indicating the emf (E_A, E_B) and impedance (Z_A,Z_B) of the backward and forward power network, the length (L) and impedance (Z_L) of the power transmission line, and the distance (d) from station (A) to the series capacitors, assured values of the distance to fault (x) and the fault resistance (R_F), data for determining the type of fault (K_f) and, in connection with the iterations, pre-determined maximally permissible difference values (S_1, S_2, S_3).

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows an impedance model of a faultless power transmission line, series-compensated with capacitors with overvoltage protection device, between two stations A and B

Figure 2 shows an impedance model of the same power transmission line when a fault has occurred between the series capacitors and station B.

Figure 3 shows an impedance model of the same power

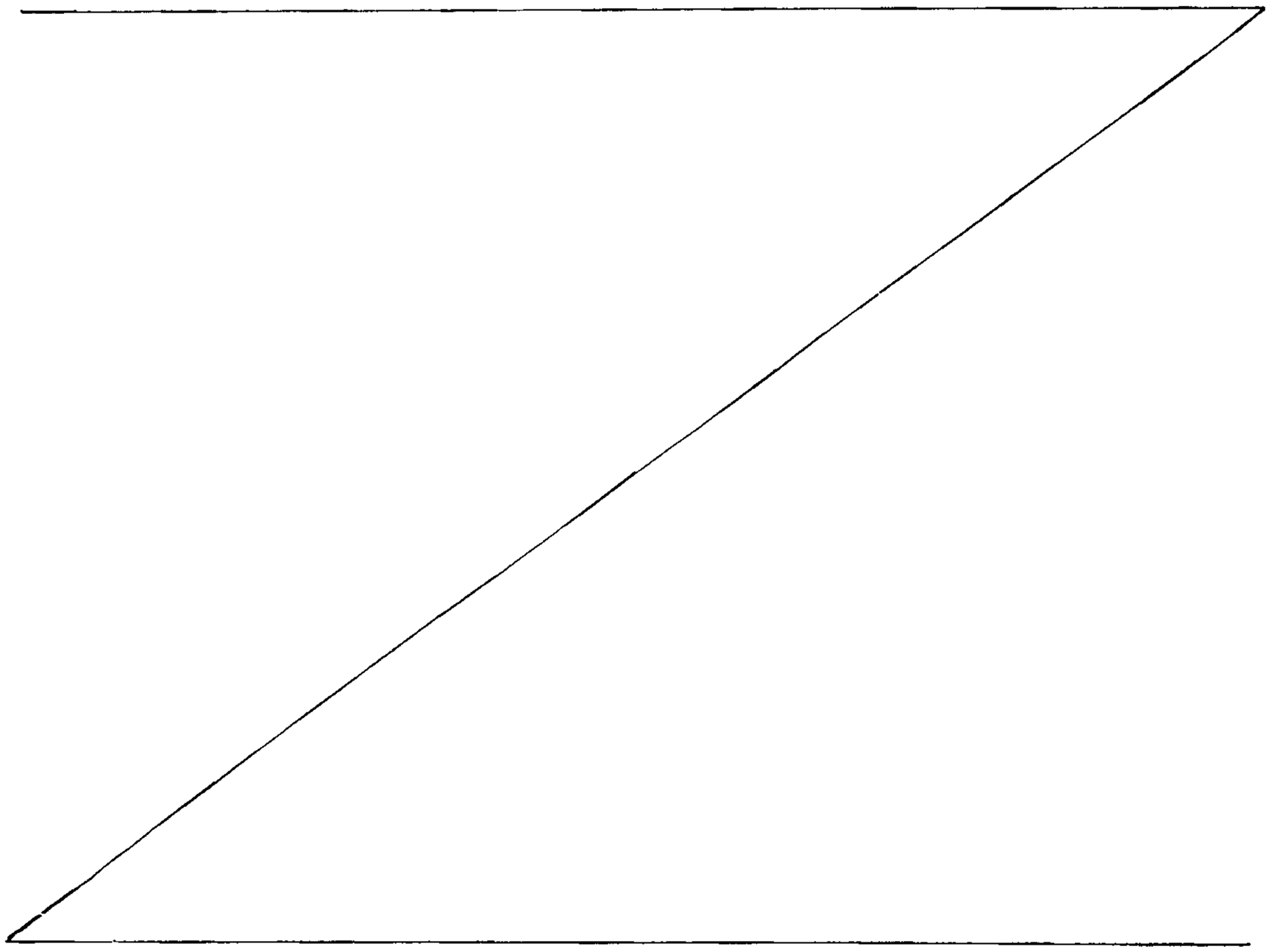
transmission line when a fault has occurred between station A and the series capacitors.

Figure 4 shows possible fault configurations on the power transmission line.

Figures 5 and 6 show how the parallel connection of the series capacitors and the overvoltage protection device may be replaced by a model-equivalent impedance consisting of a series connection of a resistance and a reactance.

Figure 7 shows how the parameters of the model equivalent as a function of a current, passing through the impedance, may be determined.

Figure 8 shows how a device for carrying out the method may be designed.



DETAILED DESCRIPTION OF THE INVENTION

A single-line diagram for a faultless power transmission line, series-compensated with capacitors, between two stations A and B is shown in Figure 1. In this context, the terms "backward" and "forward" are often used when referring to the location of a power network in relation to the power transmission line. A backward power network according to Figure 1 is represented by an emf E_A and an impedance Z_A. In a corresponding way, a forward network is represented by an emf E_B and an impedance Z_B. Further, Figure 1 shows

Z_L the impedance of the power transmission line

d the distance in per unit from station A to the series capacitors

dZ_L the impedance of the power transmission line between station A and the series-compensated capacitors.

The capacitors in series-compensated power networks are normally provided with a parallel-connected overvoltage protection device. The parallel connection will be referred to below as "SC&OVP" and is represented by a non-linear impedance because of the non-linear current/voltage characteristic of the overvoltage protection device.

Z_{sc} non-linear impedance consisting of the series capacitors and their overvoltage protection devices

$(1-d)dZ_L$
the impedance of the power transmission line between SC&OVP and station B.

The faultless power transmission line, that is, prior to the occurrence of a fault, may thus, according to Figure 1, be described, in matrix form, by the equation

$$\mathbf{E}_A - \mathbf{E}_B = \left[\mathbf{Z}_A + \mathbf{Z}_B + \mathbf{Z}_L + \mathbf{Z}_{SC_pre}\right]\mathbf{I}_{A_pre} \qquad (1)$$

The index "pre" implies that the value of the quantity in question is the value prior to the occurrence of a fault. In the following description, equations with quantities with the index "post" will also be described, which, in a corresponding manner, implies that the value of the quantity in question is the value after the occurrence of a fault. A condition for the distance-to-fault calculation is thus that a continuous measurement and storage of a number of consecutively measured voltage and current values is performed.

As regards the post-fault situation, it must be distinguished whether the fault is located between station A and SC&OVP or if the fault is located between SC&OVP and station B.

Figure 2 shows an impedance model of a series-compensated power transmission line when a fault has occurred between SC&OVP and station B. A fault which has occurred within this area will be referred to below as a fault 1. The impedance model according to Figure 2 may, in matrix form, be described with the equation

$$\mathbf{E}_A - \mathbf{E}_B = \left[\mathbf{Z}_A + x_1\mathbf{Z}_L + \mathbf{Z}_{SC_post}\right]\mathbf{I}_{A_post} - \left[(1-x_1)\mathbf{Z}_L + \mathbf{Z}_B\right]\mathbf{I}_{B_post} \qquad (2)$$

where x_1 designates the distance from the end point A of the monitored power transmission line to the fault.

Figure 3 shows an impedance model and a series-compensated power transmission line when a fault has occurred between station A and SC&OVP. A fault which has occurred within this area will be referred to below as a

fault 2. The impedance model according to Figure 3 may, in matrix form, be described with the equation

$$\mathbf{E}_A - \mathbf{E}_B = \left[\mathbf{Z}_A + x_2\mathbf{Z}_L\right]\mathbf{I}_{A_post} - \left[(1-x_2)\mathbf{Z}_L + \mathbf{Z}_B + \mathbf{Z}_{SC_post}\right]\mathbf{I}_{B_post} \qquad (3)$$

In Figures 2 and 3, the fault is represented by a fault resistance R_f to ground or zero. A fault on a three-phase line R, S and T may occur in a plurality of different ways. Figure 4 shows how a fault with a fault resistance R_R, R_S and R_T may occur between any of the phases and ground and as R_{RS}, R_{ST} etc. between different phases. A combination of the individual cases may also occur. The voltage at the fault site is defined as V_{fR}, V_{fS} and V_{fT} and the corresponding currents as I_{fR}, I_{fS} and I_{fT}

To be able to distinguish the different types of fault that may occur, the distance-to-fault calculation makes use of a fault-type matrix which has the general form

$$\mathbf{K}_f = \begin{bmatrix} k_{RR} & k_{SR} & k_{TR} \\ k_{RS} & k_{SS} & k_{TS} \\ k_{RT} & k_{ST} & k_{TT} \end{bmatrix}$$

The elements in $\mathbf{K}_f$ are determined in dependence on the type of fault as follows:

- non-diagonal elements are given the value 0 if the phase in question is not concerned by the relevant fault and the value -1 if the phase is concerned by the relevant fault
- The diagonal elements are given the value 1 if the phase in question has a fault to ground at the fault in question and to this is added the sum of the absolute values of the non-diagonal elements in the relevant line.

A few examples of a filled-in matrix $\mathbf{K}_f$ for some typical types of fault are shown below

$$\mathbf{K}_f = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \text{ for fault R-ground}$$

$$\mathbf{K}_f = \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \text{ for fault R-S-T}$$

$$\mathbf{K}_f = \begin{bmatrix} 3 & -1 & -1 \\ -1 & 3 & -1 \\ -1 & -1 & 3 \end{bmatrix} \text{ for fault R-S-T-ground}$$

$$\mathbf{K}_f = \begin{bmatrix} 1 & -1 & 0 \\ -1 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \text{ for fault R-S}$$

$$\mathbf{K}_f = \begin{bmatrix} 2 & -1 & 0 \\ -1 & 2 & 0 \\ 0 & 0 & 0 \end{bmatrix} \text{ for fault R-S-ground}$$

The vectorial relationship between the fault current I_f, i.e. I_{fR}, I_{fS} and I_{fT}, the fault voltage V_f, i.e. V_{fR}, V_{fS} and V_{fT}, the equivalent fault resistance R_f and the fault matrix is clear from the equation

$$I_f = K_f V_f / R_f \qquad (4)$$

In connection with the calculation of the distance to the fault (hereinafter referred to as the distance-to-fault calculation) which is described below, knowledge of Z_{sc} is needed, that is, the value of the non-linear impedance as a function of the actual current flowing through the impedance. One way of determining Z_{sc} is to transform the parallel connection according to Figure 5 into a model-

equivalent impedance according to Figure 6 in the form of a series connection of a resistance R_{sc} and a reactance X_{sc}. By, for example, a transient test, R_{sc} and X_{sc} may be determined individually as functions of a traversing current I_{sc}, according to Figure 7, or in the form of a corresponding analytic function. This implies that, when the current through Z_{sc} is known, Z_{sc} may be determined as

$$Z_{SC} = R_{SC} + jX_{SC} \qquad (5)$$

In case of a fault 1 according to Figure 2 och equation (2), both R_{sc} and X_{sc}, i.e. Z_{sc}, can be determined with the current I_A measured in station A.

In case of a fault 2 according to Figure 3 and equation (3), however, it is the unknown current I_B which traverses Z_{sc}. It is, therefore, an integral part of the invention to obtain a measure of the current I_B by means of an iterative process. This current is then calculated by means of equation (6) with an assumption of Z_{sc} and the distance x_2.

$$I_B = ((1 - x_2)Z_L + Z_B + Z_{SC})^{-1} \cdot ((Z_A + x_2Z_L)I_A - (E_A - E_B)) \qquad (6)$$

The value of I_B thus obtained determines, in its turn, a preliminary value of Z_{sc} in the same way as above and will be used in the calculating algorithm which will be described below for the distance-to-fault calculation.

The calculating algorithms according to the invention which calculate the distances from station A to the fault are based on the impedance models related above and corresponding equations in matrix form. Since the impedance models are different depending on whether the fault is located between SC&OVP and station B or between station A and SC&OVP, also the calculating algorithms will be different.

The calculating algorithm for calculating a fault 1, that is, calculating the distance from station A to a fault which is located between SC&OVP and station B, consists of the equations

$$\mathbf{E}_A - \mathbf{E}_B = \left[\mathbf{Z}_A + \mathbf{Z}_B + \mathbf{Z}_L + \mathbf{Z}_{SC_pre}\right]\mathbf{I}_{A_pre} \quad (1)$$

$$\mathbf{E}_A - \mathbf{E}_B = \left[\mathbf{Z}_A + x_1\mathbf{Z}_L + \mathbf{Z}_{SC_post}\right]\mathbf{I}_{A_post} - \left[(1-x_1)\mathbf{Z}_L + \mathbf{Z}_B\right]\mathbf{I}_{B_post} \quad (2)$$

$$\mathbf{V}_{A_post} - V_f = \left(x_1\mathbf{Z}_L + \mathbf{Z}_{SC_post}\right)\mathbf{I}_{A_post} \quad (7)$$

$$\mathbf{I}_f = \mathbf{I}_{A_post} + \mathbf{I}_{B_post} \quad (8)$$

where x_1 designates the unknown distance from the end point A of the monitored transmission line to the site of the fault, and V_f is obtained by means of equation (4).

If (1) is combined with (2, 4, 7, 8), a first distance-to-fault equation is obtained, after simplification, according to the following scalar quadratic equation

$$\underline{a}_1 x_1^2 - \underline{b}_1 x_1 + \underline{c}_1 - R_{f1} = 0 \quad (9)$$

where $\underline{a}_1$, $\underline{b}_1$ and $\underline{c}_1$ designate complex coefficients. By means of a first auxiliary vector

$$\mathbf{D}_1 = (\mathbf{Z}_A + \mathbf{Z}_B + \mathbf{Z}_L)(\mathbf{I}_{A_post} - \mathbf{I}_{A_pre}) + \mathbf{Z}_{SC_post}\mathbf{I}_{A_post} - \mathbf{Z}_{SC_pre}\mathbf{I}_{A_pre} \quad (10)$$

and

$\mathbf{D}_1^T$ which designates the transpose matrix of $\mathbf{D}_1$

the coefficients $\underline{a}_1$, $\underline{b}_1$ och $\underline{c}_1$ may be calculated as follows

$$\underline{a}_1 = \frac{\mathbf{D}_1^T}{\mathbf{D}_1^T\mathbf{D}_1}\mathbf{Z}_L\mathbf{K}_f\mathbf{Z}_L\mathbf{I}_{A_post} \quad (11)$$

$$\underline{b}_1 = \frac{\mathbf{D}_1^T}{\mathbf{D}_1^T\mathbf{D}_1}(\mathbf{Z}_L\mathbf{K}_f\left[\mathbf{V}_{A_post} + \left(\mathbf{Z}_L - \mathbf{Z}_{SC_post}\right)\mathbf{I}_{A_post}\right] + \mathbf{Z}_B\mathbf{K}_f\mathbf{Z}_L\mathbf{I}_{A_post}) \quad (12)$$

$$\underline{c}_1 = \frac{\mathbf{D}_1^T}{\mathbf{D}_1^T\mathbf{D}_1}(\mathbf{Z}_L + \mathbf{Z}_B)(\mathbf{V}_{A_post} - \mathbf{Z}_{SC_post}\mathbf{I}_{A_post})\mathbf{K}_f \qquad (13)$$

The first distance-to-fault equation is solved by means of an iterative process which is to be described in greater detail below. Of the two solutions of the quadratic equation, only one gives a practical solution, namely a distance to fault equal to

$$x_{11} = \frac{\mathrm{Im}(b_1) - \sqrt{\mathrm{Im}(b_1)\mathrm{Im}(b_1) - 4\,\mathrm{Im}(a_1)\mathrm{Im}(c_1)}}{2\,\mathrm{Im}(a_1)} \qquad (14)$$

where $\mathrm{Im}(a_1)$, $\mathrm{Im}(b_1)$ och $\mathrm{Im}(c_1)$ are equal to the imaginary part of the coefficients.

It has been found out that the second root of the distance-to-fault equation (9) gives unreasonable values of the distance to the fault and that the equation (14) therefore represents a sought solution to the first distance-to-fault equation (9).

By inserting the obtained value x_{11} into the first distance-to-fault equation (9), a corresponding fault resistance R_{f1} is obtained by the relationship

$$R_{f1} = \mathrm{Re}(a_1)x_{11}^2 - \mathrm{Re}(b_1)x_{11} + \mathrm{Re}(c_1) \qquad (15)$$

where $\mathrm{Re}(a_1)$, $\mathrm{Re}(b_1)$ and $\mathrm{Re}(c_1)$ are equal to the real part of the coefficients.

Determination of distance to fault and fault resistance is made by an iterative process which will be described below.

The calculating algorithm for the distance-to-fault calculation in case of fault 2 consists of the following equation system:

$$\mathbf{E}_A - \mathbf{E}_B = \left[\mathbf{Z}_A + \mathbf{Z}_B + \mathbf{Z}_L + \mathbf{Z}_{SC_pre}\right]\mathbf{I}_{A_pre} \qquad (1)$$

$$\mathbf{E}_A - \mathbf{E}_B = \left[\mathbf{Z}_A + x_2\mathbf{Z}_L\right]\mathbf{I}_{A_post} - \left[(1-x_2)\mathbf{Z}_L + \mathbf{Z}_B + \mathbf{Z}_{SC_post}\right]\mathbf{I}_{B_post} \quad (3)$$

$$\mathbf{V}_{A_post} - V_f = x_2\mathbf{Z}_L\mathbf{I}_{A_post} \quad (16)$$

$$\mathbf{I}_f = \mathbf{I}_{A_post} + \mathbf{I}_{B_post} \quad (17)$$

where x_2 designates the unknown distance from the end point A of the monitored transmission line to the site of the fault, and V_f is obtained by means of equation (4). If (1) is combined with (3, 5, 16, 17), a second distance-to-fault equation is obtained, after simplification, according to the following scalar quadratic equation with x_2 as variable

$$\underline{a}_2 x_2^2 - \underline{b}_2 x_2 + \underline{c}_2 - R_{f2} = 0 \quad (18)$$

where $\underline{a}_2$, $\underline{b}_2$ and $\underline{c}_2$ designate complex coefficients. By means of a second auxiliary vector

$$\mathbf{D}_2 = (\mathbf{Z}_A + \mathbf{Z}_B + \mathbf{Z}_L)(\mathbf{I}_{A_post} - \mathbf{I}_{A_pre}) + \mathbf{Z}_{SC_post}\mathbf{I}_{A_post} - \mathbf{Z}_{SC_pre}\mathbf{I}_{A_pre} \quad (19)$$

and

$\mathbf{D}_2^T$ which designates the transpose matrix of $\mathbf{D}_2$

the coefficients $\underline{a}_2$, $\underline{b}_2$ och $\underline{c}_2$ may be calculated as follows:

$$\underline{a}_2 = \frac{\mathbf{D}_2^T}{\mathbf{D}_2^T\mathbf{D}_2}\mathbf{Z}_L\mathbf{K}_f\mathbf{Z}_L\mathbf{I}_{A_post} \quad (20)$$

$$\underline{b}_2 = \frac{\mathbf{D}_2^T}{\mathbf{D}_2^T\mathbf{D}_2}(\mathbf{Z}_L\mathbf{K}_f\mathbf{V}_{A_post} + \left[\mathbf{Z}_L + \mathbf{Z}_{SC_post} + \mathbf{Z}_B\right]\mathbf{K}_f\mathbf{Z}_L\mathbf{I}_{A_post}) \quad (21)$$

$$\underline{c}_2 = \frac{\mathbf{D}_2^T}{\mathbf{D}_2^T\mathbf{D}_2}(\mathbf{Z}_L + \mathbf{Z}_B + \mathbf{Z}_{SC_post})\mathbf{K}_f\mathbf{V}_{A_post} \quad (22)$$

The solution to the second distance-to-fault equation (16) gives a sought distance to the site of the fault as

$$x_{21} = \frac{\mathrm{Im}(b_2) - \sqrt{\mathrm{Im}(b_2)\mathrm{Im}(b_2) - 4\,\mathrm{Im}(a_2)\mathrm{Im}(c_2)}}{2\,\mathrm{Im}(a_2)} \qquad (23)$$

It has been found out that the second root of the distance-to-fault equation (18) gives unreasonable values of the distance to the fault and that the equation (23) therefore represents a sought solution to the first distance-to-fault equation (18).

By inserting the obtained value x_{21} into the second distance-to-fault equation (18), the corresponding fault resistance R_{f2} is obtained by the relationship

$$R_{f2} = \mathrm{Re}(a_2)x_{21}^2 - \mathrm{Re}(b_2)x_{21} + \mathrm{Re}(c_2) \qquad (24)$$

Determination of distance to fault and fault resistance is made by an iterative process which will be described below.

Before the iterative process for calculating the distance to fault can be started, a number of conditions must be fulfilled:

Independently of whether the fault is a category 1 fault or a category 2 fault, information about the value of fixed parameters, included in the equation systems, must be available. This relates to values of the backward and forward power networks, the length of the power transmission line, the impedance, the distance from station A to the series capacitors, and so on.

An assumption must be made on an initial value of distance to fault and fault resistance. This assumption may be made with arbitrary values within permissible limits.

When a fault has occurred, the type of fault and hence also the $\mathbf{K}_f$ matrix may be determined.

To be able to determine which of the calculating algorithms is to be used, knowledge must be gained as to on which side of SC&OVP the fault has occurred, that is, whether it is a fault 1 or a fault 2.

There must be a continuous access, both before and after a fault has occurred, of filtered values of current and voltage measured in one of the stations (A).

After the above conditions have been fulfilled, the distance-to-fault calculation is initiated.

In case of a fault 1, the following occurs:

Based on the current I_A measured in station A after the occurrence of the fault, R_{sc} and X_{sc} are determined, for example with Figure 7, whereupon Z_{sc} in equation (2) may be determined.

- the D_1 auxiliary vectors are calculated according to equation (10)

- the coefficients a_1, b_1 and c_1 for the first distance-to-fault equation (9) are calculated according to equations (11), (12) and (13)

- a first calculated value of the distance to the fault is calculated according to equation (14), and

- a first value of the fault resistance is calculated according to equation (15).

The first calculated value of the distance to the fault is compared with the assumed value of the distance to the fault. If the difference between the values is greater than a pre-set maximally permissible difference value S_1, the assumed value in equations (2) and (7) is replaced by

the first calculated value of the distance to the fault and the fault resistance.

Thereafter, a new calculation procedure is carried out according to the above, which provides new values of the distance to the fault and the fault resistance. If the difference between the last calculated value of the distance to the fault and the first calculated value is greater than the maximally permissible difference value, the first calculated value in equations (2) and (7) is replaced by the last calculated values of the distance to fault and the fault resistance.

This iteration continues until the difference value of two consecutive calculation procedures is smaller than the set maximally permissible difference value, whereupon the last calculated values of the distance to fault and the fault resistance are regarded as the real values.

In case of a fault 2, the following occurs:

Based on the current I_A measured in station A and an assumption of Z_{sc}, after the occurrence of the fault, a preliminary value of the current through Z_{sc} is calculated by means of equation (5). By means of the preliminary value of the current, a first value of R_{sc} and X_{sc}, that is also Z_{sc}, may be obtained. The first calculated values are compared with the assumed value of Z_{sc}. If the difference between the values is greater than a preset maximally permissible difference value S_2, the set value in equation (6) is replaced by the first calculated value of Z_{sc}. This iteration continues until the difference value of two consecutive calculation procedures is smaller than the set maximally permissible difference value, whereupon the last calculated value of Z_{sc} constitutes the assumption of Z_{sc} which is needed in equations (3) and (16).

- the D_2 auxiliary vectors are calculated according to

equation (19)

- the coefficients a_2, b_2 and c_2 of the second distance-to-fault equation (18) are calculated according to equations (20), (21) and (22)

- a first calculated value of the distance to the fault is calculated according to equation (23), and

- a first value of the fault resistance is calculated according to equation (22).

The first calculated value of the distance to the fault is compared with the set value of the distance to the fault. If the difference between the values is greater than a pre-set maximally permissible difference value S_3, the set value in equations (3) and (16) is replaced by the first calculated value of the distance to the fault and the fault resistance.

Thereafter, a new calculation procedure is carried out according to the above, which provides new values of the distance to the fault and the fault resistance. If the difference between the last calculated value of the distance to the fault and the first calculated value is greater than the maximally permissible difference value, the first calculated value in equations (3) and (16) is replaced by the last calculated values of the distance to fault and the fault resistance.

This iteration continues until the difference value of two consecutive calculation procedures is smaller than the set maximally permissible difference value, whereupon the last calculated values of the distance to fault and the fault resistance are regarded as the real values.

With access to the calculated values of the distances to fault, x_{11} and x_{21}, and the corresponding fault resistances

R_{f1} and R_{f2} and the equations described in the description, there is, according to the invention, a method for determining which of the distance-to-fault values represents the actual distance to the fault. The method is different depending on whether the fault is a three-phase fault or if it is an unsymmetrical fault, that is, if one or more phases is/are faultless.

If the fault is a three-phase fault, the following occurs:

Is $R_{f1} > R_{f2}$? Yes

If the answer is yes, it is assumed, as a first assumption, that the fault is a fault 2 and it is asked whether $R_{f2} > R_0$? where R_0 is a preset minimum value. If the answer is yes, the fault is a fault 2, that is, the calculated value of x_{21} is the true value of the distance to the fault. If the answer is no, it is a fault 1, that is, the calculated value of x_{11} is the true value of the distance to the fault.

Is $R_{f1} > R_{f2}$? No

If the answer is no, it is assumed, as a first assumption, that the fault is a fault 1 and it is asked whether $R_{f1} > R_0$? where R_0 is a preset minimum value. If the answer is yes, the fault is a fault 1, that is, the calculated value of x_1 is the true value of the distance to the fault. If the answer is no, it is a fault 2, that is, the calculated value of x_{21} is the true value of the distance to the fault.

If the fault is an unsymmetrical fault, the currents through the fault resistances must first be determined for the two cases of fault.

For fault 1, the phase currents through the fault resistance may be determined with the aid of

$$i_{f(R,S,T)1} = i_{A(R,S,T)} + i_{B(R,S,T)1} \qquad (25)$$

where

$i_{A(R,S,T)}$ are the phase currents measured in station A

$i_{B(R,S,T)1}$ is determined with the aid of equation (2) ($i_B = I_{B\text{-}post}$)

and for fault 2, the phase currents through the fault resistance may be determined with the aid of

$$i_{f(R;S;T)2} = = i_{A(R,S,T)} + i_{B(R,S,T)2} \qquad (26)$$

where

$i_{B(R,S,T)2}$ is determined with the aid of equation (3) ($i_B = I_{B\text{-}post}$)

The method for determining whether it is a question of a fault 1 or a fault 2 comprises, after a faultless phase has been identified in conventional manner, first determining the currents at the site of the fault in the faultless phase or phases for the two cases of fault according to equations (25), (2) and (26), (3), that is i_{ff1} och i_{ff2}. Then follows the following procedure:

Is $i_{ff1} > i_{ff2}$?

Now, if $i_{ff1} > i_{ff2}$ it is considered, as a first assumption, that the fault is a fault 2 and if $i_{ff1} < i_{ff2}$, it is considered, as a first assumption, that the fault is a fault 1.

The continued determination procedure is exactly identical with the procedure when the fault is a three-phase fault, that is:

In case of a fault 2, it is asked whether $R_{f2} > R_0$? where R_0 is a preset minimum value. If the answer is yes, the fault is a fault 2, that is, the calculated value of x_{21} is the true value of the distance to the fault. If the answer is no, it is a fault 1, that is, the calculated value of x_{11} is the true value of the distance to the fault.

In case of a fault 1, it is asked whether $R_{f1} > R_0$? where R_0 is a preset minimum value. If the answer is yes, the fault is a fault 1, that is, the calculated value of x_{11} is the true value of the distance to the fault. If the answer is no, it is a fault 2, that is, the calculated value of x_{21} is the true value of the distance to the fault.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A device for determining the distance from a station, at one end of a transmission line, until the occurrence of a fault on the transmission line according to the described method comprises certain measuring devices, measurement value converters, members for iterative treatment of the calculating algorithms of the method, a possibility of inputting to the member known conditions regarding the parameters of the power networks and assumed values of distance to fault, fault resistance, etc., a VDU indicating the calculated distance to fault, and a printer for printout of the calculated distance to fault. Figure 8 largely shows an embodiment of the device. Embodiments similar to those of Figure 8 are within the scope of the invention.

Figure 8 shows a transmission line 1 between two stations A and B. The line is provided with capacitors, protecting against overvoltages, forming the impedance Z_{SC}. Station A accommodates measuring devices 2 and 3 for continuous measurement of all the phase currents and phase voltages. In the measurement converters 4 and 5, a number of these consecutively measured values, which in case of a fault are passed to a calculating unit 6, are filtered and stored. The calculating unit is provided with the calculating algorithms described, programmed for the iterative processes which are needed for calculating the distance to fault and the fault resistance.

Even before a fault occurred on the transmission line, the calculating unit was provided with a number of conditions and assumptions to be able to perform the calculation of the distance to fault etc. These conditions comprise values of the emf and the impedance of both a forward and a backward power network. The calculating unit is also supplied with known values of the length and impedance of the transmission line, the distance from station A to the series capacitors, set values of the distance to fault, the fault resistance, Z_{SC} and the maximally permissible difference values S_1, S_2 and S_3. In connection with the occurrence of a fault, information about the type of fault may be supplied to the calculating unit for determining the fault-type matrix K_f. In addition, after the occurrence of the fault, information is supplied as to whether the fault is positioned between the series capacitors and station B or whether the fault is positioned between station A and the series capacitors, that is, whether the fault is a fault 1 or a fault 2.

Then, when a fault has occurred, and the external conditions are fulfilled, the calculating procedure starts with the necessary iterations to obtain difference values which fall below the maximally permissible ones. The finally calculated values will then be transferred to a VDU which shows the distance to the fault and the magnitude of the fault resistance, respectively, for further actions. The device also comprises possibilities for printout of the result.

In the similar embodiments indicated above, parts of the embodiment according to Figure 8 may be more or less integrated in the calculating unit.

CLAIMS

1. A method for location of a fault, and determination of a resultant fault resistance, which has occurred on a power transmission line which is series-compensated with a capacitor, with a parallel-connected overvoltage protection device, between two stations (A) and (B), wherein the distance to the fault from one station (A) and the fault resistance are determined by means of values measured in said station (A) of voltage before and voltage and current after the occurrence of the fault, **characterized** in that, if the fault occurred between the series capacitors and station B, the distance to the fault is determined by

$$x_{11} = \frac{\mathrm{Im}(\underline{b}_1) - \sqrt{\mathrm{Im}(\underline{b}_1)\mathrm{Im}(\underline{b}_1) - 4\,\mathrm{Im}(\underline{a}_1)\mathrm{Im}(\underline{c}_1)}}{2\,\mathrm{Im}(\underline{a}_1)} \qquad (14)$$

which is the solution to a first distance-to-fault equation

$$\underline{a}_1 x_1^2 - \underline{b}_1 x_1 + \underline{c}_1 - R_{f1} = 0 \qquad (9)$$

where $\underline{a}_1$, $\underline{b}_1$ and $\underline{c}_1$ designate complex coefficients which, via a first auxiliary vector

$$\mathbf{D}_1 = (\mathbf{Z}_A + \mathbf{Z}_B + \mathbf{Z}_L)(\mathbf{I}_{A_post} - \mathbf{I}_{A_pre}) + \mathbf{Z}_{SC_post}\mathbf{I}_{A_post} - \mathbf{Z}_{SC_pre}\mathbf{I}_{A_pre} \qquad (10)$$

and

$\mathbf{D}_1^T$, which designates the transpose matrix of $\mathbf{D}_1$,

may be calculated as follows

$$\underline{a}_1 = \frac{\mathbf{D}_1^T}{\mathbf{D}_1^T\mathbf{D}_1}\mathbf{Z}_L\mathbf{K}_f\mathbf{Z}_L\mathbf{I}_{A_post} \qquad (11)$$

$$\underline{b}_1 = \frac{\mathbf{D}_1^T}{\mathbf{D}_1^T\mathbf{D}_1}(\mathbf{Z}_L\mathbf{K}_f\left[\mathbf{V}_{A_post} + \left(\mathbf{Z}_L - \mathbf{Z}_{SC_post}\right)\mathbf{I}_{A_post}\right] + \mathbf{Z}_B\mathbf{K}_f\mathbf{Z}_L\mathbf{I}_{A_post}) \qquad (12)$$

$$\underline{c}_1 = \frac{\mathbf{D}_1^T}{\mathbf{D}_1^T\mathbf{D}_1}(\mathbf{Z}_L + \mathbf{Z}_B)(\mathbf{V}_{A_post} - \mathbf{Z}_{SC_post}\mathbf{I}_{A_post})\mathbf{K}_f \qquad (13)$$

where:

Z_A is equal to a source impedance of a backward power network,

Z_B is equal to a source impedance of a forward power network,

Z_L is equal to an impedance of the power transmission line,

index post identifies a value after the occurrence of a fault,

index pre identifies a value before the occurrence of a fault,

I_A is equal to a fault current,

Z_{sc} is equal to a non-linear impedance,

K_f is equal to a fault-type matrix,

and where $Im(a_1)$, $Im(b_1)$ and $Im(c_1)$ are equal to the imaginary part of the coefficients, and that

the fault resistance becomes equal to

$$R_{f1} = \mathrm{Re}(a_1)x_{11}^2 - \mathrm{Re}(b_1)x_{11} + \mathrm{Re}(c_1) \qquad (15)$$

where $Re(a_1)$, $Re(b_1)$ and $Re(c_1)$ are equal to the real part of the coefficients.

2. A method for location of a fault, and determination of a resultant fault resistance, which has occurred on a power transmission line which is series-compensated with a capacitor, with a parallel-connected overvoltage protection device, between two stations (A) and (B), wherein the distance to the fault from one station (A) and the fault resistance are determined by means of values measured in said station (A) of voltage before and

voltage and current after the occurrence of the fault, **characterized** in that, if the fault occurred between station A and the series capacitors, the distance to the fault is determined by

$$x_{21} = \frac{\mathrm{Im}(\underline{b}_2) - \sqrt{\mathrm{Im}(\underline{b}_2)\mathrm{Im}(\underline{b}_2) - 4\,\mathrm{Im}(\underline{a}_2)\mathrm{Im}(\underline{c}_2)}}{2\,\mathrm{Im}(\underline{a}_2)} \qquad (23)$$

which is the solution to a second distance-to-fault equation

$$\underline{a}_2 x_2^2 - \underline{b}_2 x_2 + \underline{c}_2 - R_{f2} = 0 \qquad (18)$$

where $\underline{a}_2$, $\underline{b}_2$ och $\underline{c}_2$ designate complex coefficients which, with the aid of a second auxiliary vector

$$\mathbf{D}_2 = (\mathbf{Z}_A + \mathbf{Z}_B + \mathbf{Z}_L)(\mathbf{I}_{A_post} - \mathbf{I}_{A_pre}) + \mathbf{Z}_{SC_post}\mathbf{I}_{A_post} - \mathbf{Z}_{SC_pre}\mathbf{I}_{A_pre} \qquad (19)$$

and

$\mathbf{D}_2^T$, which designates the transpose matrix of $\mathbf{D}_2$,

the coefficients $\underline{a}_2$, $\underline{b}_2$ and $\underline{c}_2$ may be calculated as follows:

$$\underline{a}_2 = \frac{\mathbf{D}_2^T}{\mathbf{D}_2^T\mathbf{D}_2}\mathbf{Z}_L\mathbf{K}_f\mathbf{Z}_L\mathbf{I}_{A_post} \qquad (20)$$

$$\underline{b}_2 = \frac{\mathbf{D}_2^T}{\mathbf{D}_2^T\mathbf{D}_2}(\mathbf{Z}_L\mathbf{K}_f\mathbf{V}_{A_post} + \left[\mathbf{Z}_L + \mathbf{Z}_{SC_post} + \mathbf{Z}_B\right]\mathbf{K}_f\mathbf{Z}_L\mathbf{I}_{A_post}) \qquad (21)$$

$$\underline{c}_2 = \frac{\mathbf{D}_2^T}{\mathbf{D}_2^T\mathbf{D}_2}(\mathbf{Z}_L + \mathbf{Z}_B + \mathbf{Z}_{SC_post})\mathbf{K}_f\mathbf{V}_{A_post} \qquad (22)$$

where:

Z_A is equal to a source impedance of a backward power network,

Z_B is equal to a source impedance of a forward power network,

Z_L is equal to an impedance of the power transmission line,

index post identifies a value after the occurrence of a fault,

index pre identifies a value before the occurrence of a fault,

I_A is equal to a fault current,

Z_{SC} is equal to a non-linear impedance,

K_f is equal to a fault-type matrix,

and where $Im(a_2)$, $Im(b_2)$ and $Im(c_2)$ are equal to the imaginary part of the coefficients, and that

the fault resistance becomes

$$R_{f2} = Re(a_2)v_{21}^2 - Re(b_2)v_{21} + Re(c_2) \qquad (24)$$

where $Re(a_2)$, $Re(b_2)$ and $Re(c_2)$ are equal to the real part of the coefficients.

3. A method for location of a fault, and determination of the resultant fault resistance, which has occurred on a series-compensated power transmission line according to any of claims 1 or 2, **characterized** in that the method and the determination presuppose knowledge of

$E_{A(P,\ S,\ T)}$ the emf of the backward power network

$Z_{A(P,\ S,\ T)}$ the source impedances of the backward power network

$E_{B(P,\ S,\ T)}$ the emf of the forward power network

$Z_{B(P,\ S,\ T)}$ the source impedances of the forward power network

Z_L the impedance of the power transmission line

d the distance in per unit from station A up to the series capacitors

dZ_L the impedance of the power transmission line between station A and the series-compensated capacitors

$(1 - d)dZ_L$ the impedance of the power transmission line between the series capacitors and station B.

4. A method for location of a fault, and determination of the resultant fault resistance, which has occurred on a series-compensated power transmission line according to any of claims 1 or 2, **characterized** in that, when a fault has occurred, in order to characterize which type of fault has occurred, the fault-type matrix is determined as follows

$$K_f = \begin{bmatrix} k_{RR} & k_{SR} & k_{TR} \\ k_{RS} & k_{SS} & k_{TS} \\ k_{RT} & k_{ST} & k_{TT} \end{bmatrix}$$

where the elements in K_t are determined depending on the type of fault according to

- non-diagonal elements are given the value 0 if the phase in question is not concerned by the relevant fault and the value -1 if the phase is concerned by the relevant fault
- The diagonal elements are given the value 1 if the phase in question has a fault to ground at the fault in question and to this is added the sum of the absolute values of the non-diagonal elements in the relevant row.

5. A method for location of a fault, and determination of the resultant fault resistance, which has occurred on a series-compensated power transmission line according to any of claims 1 or 2, characterized in that the parallel connection of the series capacitors and the overvoltage protection device constitutes a non-linear impedance Z_{SC} which is represented by a model equivalent impedance in the form of a series connection of a resistance R_{SC} and a reactance X_{SC}, which may be individually determined as a function of a traversing current, whereupon the actual value of resistance and reactance may be determined with the actual current which, after the occurrence of the fault, flows through the impedance, whereby the non-linear impedance may be set as

$$Z_{sc} = R_{sc} + jX_{sc}m \qquad (5).$$

6. A method for location of a fault, and determination of the resultant fault resistance, which has occurred on a series-compensated power transmission line according to claim 1, characterized in that, if the fault occurred between the series capacitors and station B, the actual current which is used for determining the non-linear impedance is the current measured in station A.

7. A method for location of a fault, and determination of the resultant fault resistance, which has occurred on a series-compensated power transmission line according to claim 2, characterized in that, if the fault occurred between station A and the series capacitors, the actual current which is used for determining the non-linear impedance is a current I_B calculated in station B according to

$$I_B = ((1 - x_2)Z_L + Z_B + Z_{SC})^{-1} \cdot ((Z_A + x_2 Z_L)I_A - (E_A - E_B)) \qquad (6)$$

with an assumption on Z_{SC} and on a distance to fault, x_2, which current is then used for determining a new value of Z_{SC} which is compared with the assumed value of Z_{SC}, and if

the difference between the assumed value of Z_{sc} and the new value is greater than a maximally permissible difference value S_2, the assumed value in equation (6) is replaced by the first calculated value of Z_{sc}, which method is repeated until the difference value of two consecutive calculating procedures is smaller than the set maximally permissible difference value, whereupon the last obtained value of Z_{sc} constitutes the assumption which is needed for a final determination of the distance to fault and the fault resistance.

8. A method for location of a fault, and determination of the resultant fault resistance, which has occurred on a series-compensated power transmission line according to any of claims 1 or 2, **characterized** in that an assumption is made on a distance to fault "x" from station A and a fault resistance R_f.

9. A method for location of a fault, and determination of the resultant fault resistance, which has occurred on a series-compensated power transmission line according to any of claims 1 or 2, **characterized** in that, if the fault occurred between the series capacitors and station A, the calculation of the actual distance to fault and the fault resistance is based on a calculating algorithm which comprises the equations

$$\mathrm{E}_A - \mathrm{E}_B = \left[\mathrm{Z}_A + \mathrm{Z}_B + \mathrm{Z}_L + \mathrm{Z}_{SC_pre}\right]\mathrm{I}_{A_pre} \qquad (1)$$

$$\mathrm{E}_A - \mathrm{E}_B = \left[\mathrm{Z}_A + x_1\mathrm{Z}_L + \mathrm{Z}_{SC_post}\right]\mathrm{I}_{A_post} - \left[\left(1 - x_1\right)\mathrm{Z}_L + \mathrm{Z}_B\right]\mathrm{I}_{B_post} \qquad (2)$$

$$\mathrm{V}_{A_post} - V_f = \left(x_1\mathrm{Z}_L + \mathrm{Z}_{SC_post}\right)\mathrm{I}_{A_post} \qquad (7)$$

$$\mathrm{I}_f = \mathrm{I}_{A_post} + \mathrm{I}_{B_post} \qquad (8)$$

where quantities with the index "pre" relate to the value prevailing before a fault has occurred and where quantities with the index "post" relate to the value prevailing immediately after the fault has occurred, and where (1) is the vectorial equation of the power transmission line corresponding to the conditions immediately before the fault has occurred, and
where (2) is the vectorial equation of the power transmission line corresponding to the conditions immediately after the fault has occurred, and
where V_A represents voltage measured in station A, and
where V_f relates to the voltage on the power transmission line where the fault has occurred and which is determined with the aid of

$$I_f = K_f V_f / R_f \qquad (4)$$

where I_f relates to the fault current through the fault resistance, and
where x_1 designates the unknown distance to fault from the end point A of the power transmission line to the site of the fault.

10. A method for location of a fault, and determination of the resultant fault resistance, which has occurred on a series-compensated power transmission line according to any of claims 1 or 2, **characterized** in that, if the fault occurred between station A and the series capacitors, the calculation of the actual distance to fault and the fault resistance is based on a calculating algorithm which comprises the equations

$$\mathbf{E}_A - \mathbf{E}_B = \left[\mathbf{Z}_A + \mathbf{Z}_B + \mathbf{Z}_L + \mathbf{Z}_{SC_pre}\right]\mathbf{I}_{A_pre} \qquad (1)$$

$$\mathbf{E}_A - \mathbf{E}_B = \left[\mathbf{Z}_A + x_2\mathbf{Z}_L\right]\mathbf{I}_{A_post} - \left[(1-x_2)\mathbf{Z}_L + \mathbf{Z}_B + \mathbf{Z}_{SC_post}\right]\mathbf{I}_{B_post} \qquad (3)$$

$$\mathbf{V}_{A_post} - V_f = x_2 \mathbf{Z}_L \mathbf{I}_{A_post} \tag{16}$$

$$\mathbf{I}_f = \mathbf{I}_{A_post} + \mathbf{I}_{B_post} \tag{17}$$

where quantities with the index "pre" relate to the value prevailing before a fault has occurred and where quantities with the index "post" relate to the value prevailing immediately after the fault has occurred, and where (1) is the vectorial equation of the power transmission line corresponding to the conditions immediately before the fault has occurred, and where (2) is the vectorial equation of the power transmission line corresponding to the conditions immediately after the fault has occurred, and where V_A represents voltage measured in station A, and where V_f relates to the voltage on the power transmission line where the fault has occurred and which is determined with the aid of

$$I_f = K_f \, V_f / R_f \tag{4}$$

where I_f relates to the fault current through the fault resistance, and where x_2 designates the unknown distance to fault from the end point A of the power transmission line to the site of the fault.

11. A method for determining which of a located fault according to claim 1 or claim 2 represents the true location, **characterized** in that, if the located fault is a three-phase fault, it is asked whether R_{f1} is greater than R_{f2}, and if the answer is yes, it is assumed, as a first assumption, that the fault is an R_{f2} fault, and it is asked whether $R_{f2} > R_0$ where R_0 is a preset minimum value, and if the answer is yes, the distance to fault is x_{21}, and if the answer is no, the distance to fault is x_{11}

and that if R_{f1} is smaller than R_{f2}, it is assumed, as a first assumption, that the fault is an R_{f1} fault, and it is asked whether $R_{f1} > R_0$ and if the answer is yes, the distance to fault is x_1, and if the answer is no, the distance to fault is x_2

if the located fault is an unsymmetrical fault, the phase currents through the fault resistance are first determined for a fault according to claim 1 according to

$$i_{f(R,S,T)1} = i_{A(R,S,T)} + i_{B(R,S,T)1} \qquad (25)$$

where

$i_{A(R,S,T)}$ are the phase currents measured in station A

$i_{B(R,S,T)1}$ is determined by means of equation (2) ($i_B = I_{B\text{-}post}$)

and for a fault according to claim 2 according to

$$i_{f(R;S;T)2} = = i_{A(R,S,T)} + i_{B(R,S,T)2} \qquad (26)$$

where

$i_{B(R,S,T)2}$ is determined by means of equation (3) ($i_B = I_{B\text{-}post}$)

whereupon it is asked
whether i_{f1} is greater than i_{f2}, and if the answer is yes, it is assumed, as a first assumption, that the fault is an R_{f2} fault, and it is asked whether $R_{f2} > R_0$ where R_0 is a preset minimum value, and if the answer is yes, the distance to fault is x_{21}, and if the answer is no, the distance to fault is x_{11}

and if i_{f1} is smaller than i_{f2}, it is assumed, as a first assumption, that the fault is an R_{f1} fault, and it is asked

whether $R_{f1} > R_0$, and if the answer is yes, the distance to fault is x_1, and if the answer is no, the distance to fault is x_2.

12. A device for carrying out the method for location of a fault, and determination of a resultant fault resistance, which has occurred on a series-compensated power transmission line between two stations A and B according to any of the preceding claims 1 - 11, **characterized** in that the device comprises measuring devices (2, 3) for continuous measurement of phase currents and phase voltages in one of the stations (A), measurement converters (4, 5) for filtering and storage of a number of these consecutively measured values, a calculating unit (6) which is provided with the calculating algorithms included in the method, including iteration possibilities, and which is arranged for receiving signals in the form of the measured, filtered and stored pre-fault phase currents and phase voltages as well as measured and filtered values of post-fault phase currents and phase voltages as well as signals indicating the emf (E_A, E_B) and impedance (Z_A, Z_B) of the backward and forward power network, the length (L) and impedance (Z_L) of the power transmission line, and the distance (d) from station A to the series capacitors, assumed values of the distance to fault (x) and the fault resistance (R_f), data for determining the type of fault (K_f) and, in connection with the iterations, pre-determined maximally permissible difference values (S_1, S_2, S_3).

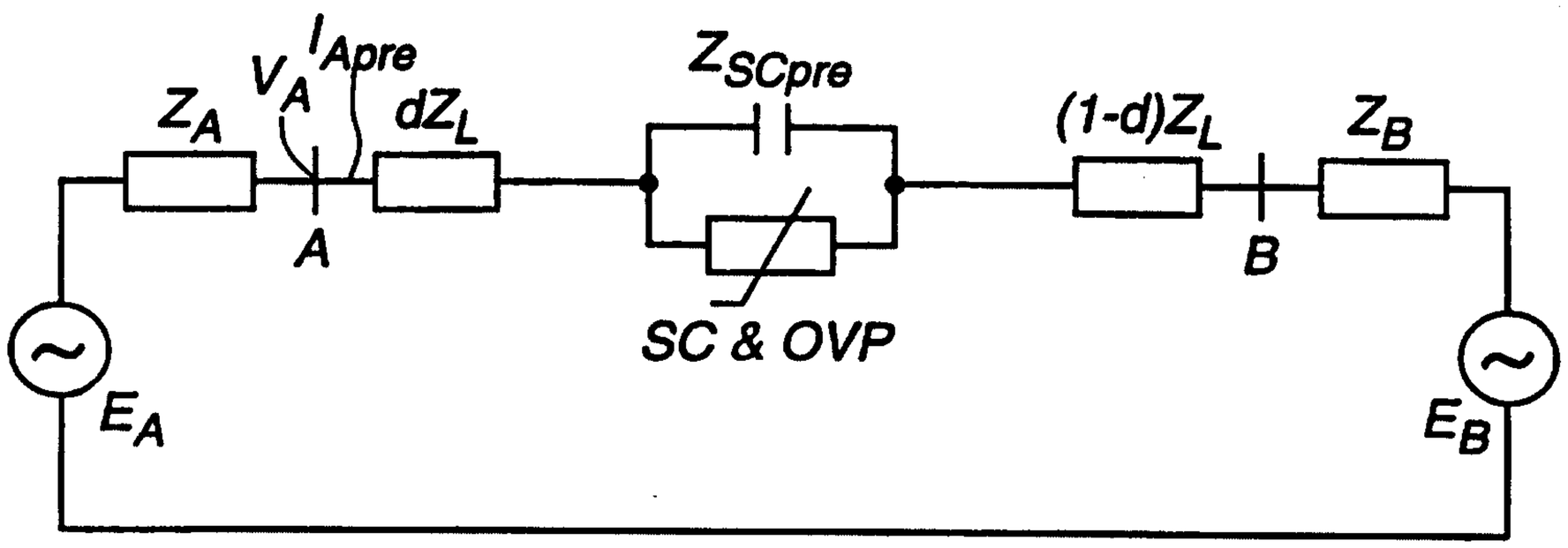


Fig. 1

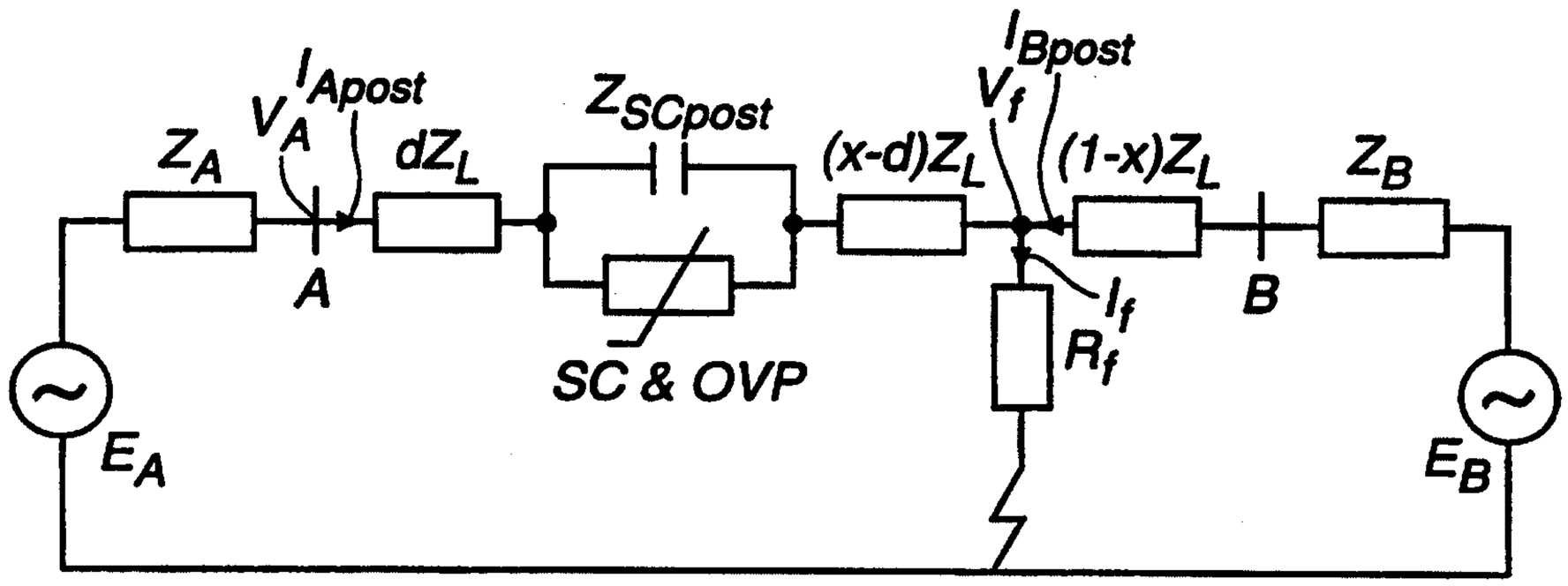


Fig. 2

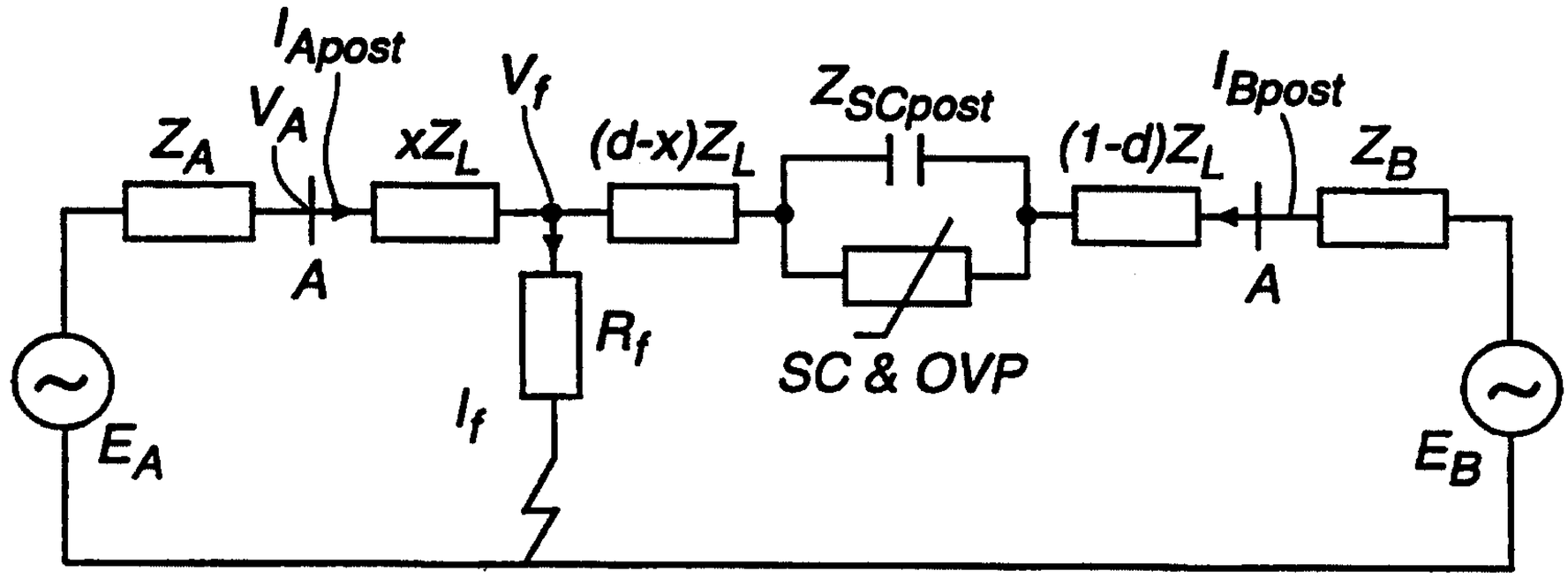


Fig. 3

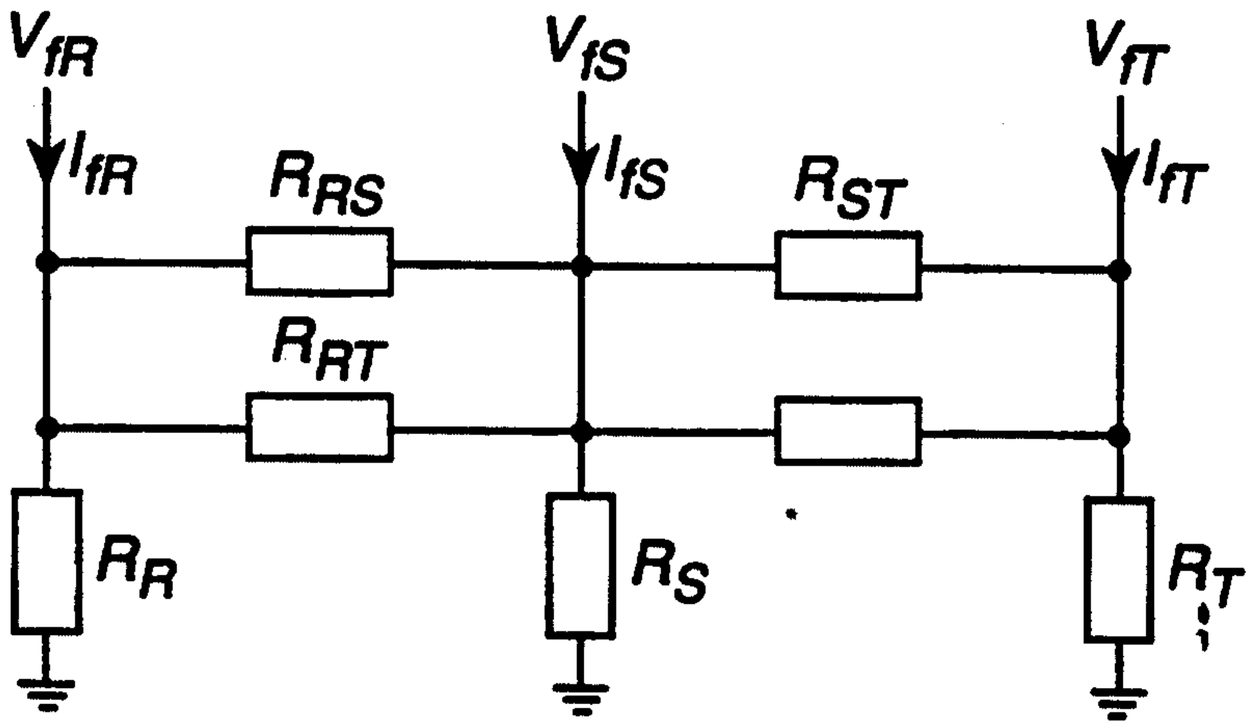


Fig. 4

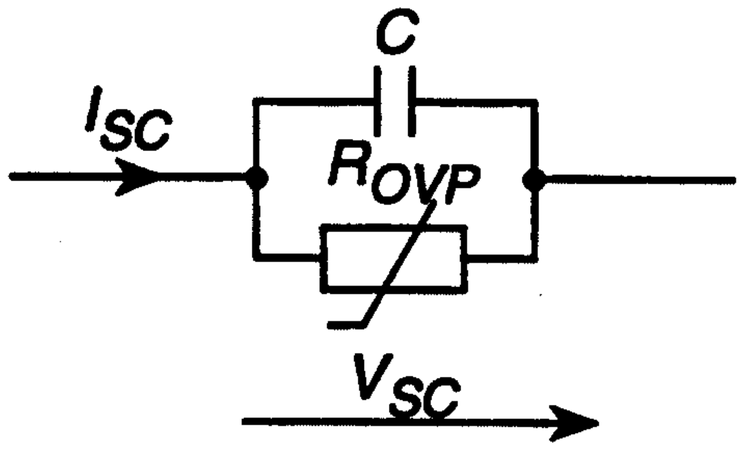


Fig. 5

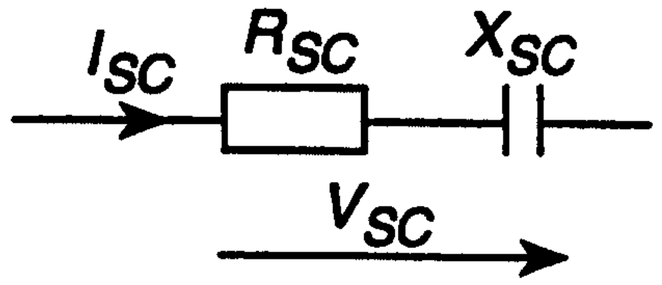


Fig. 6

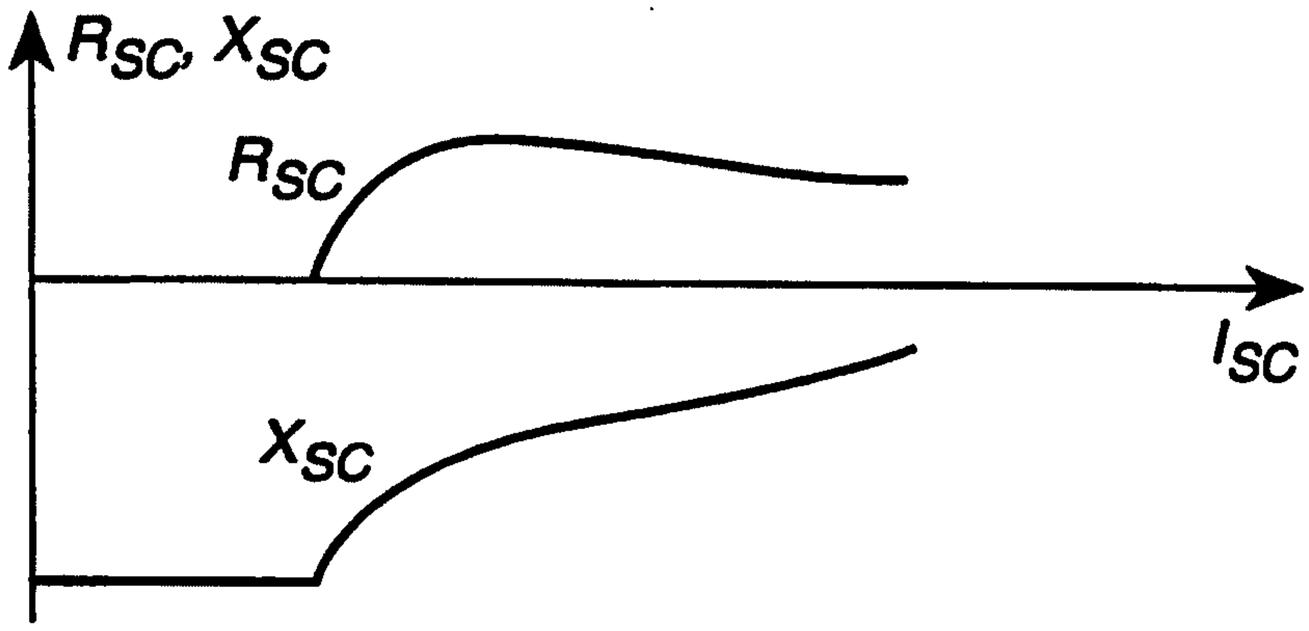


Fig. 7

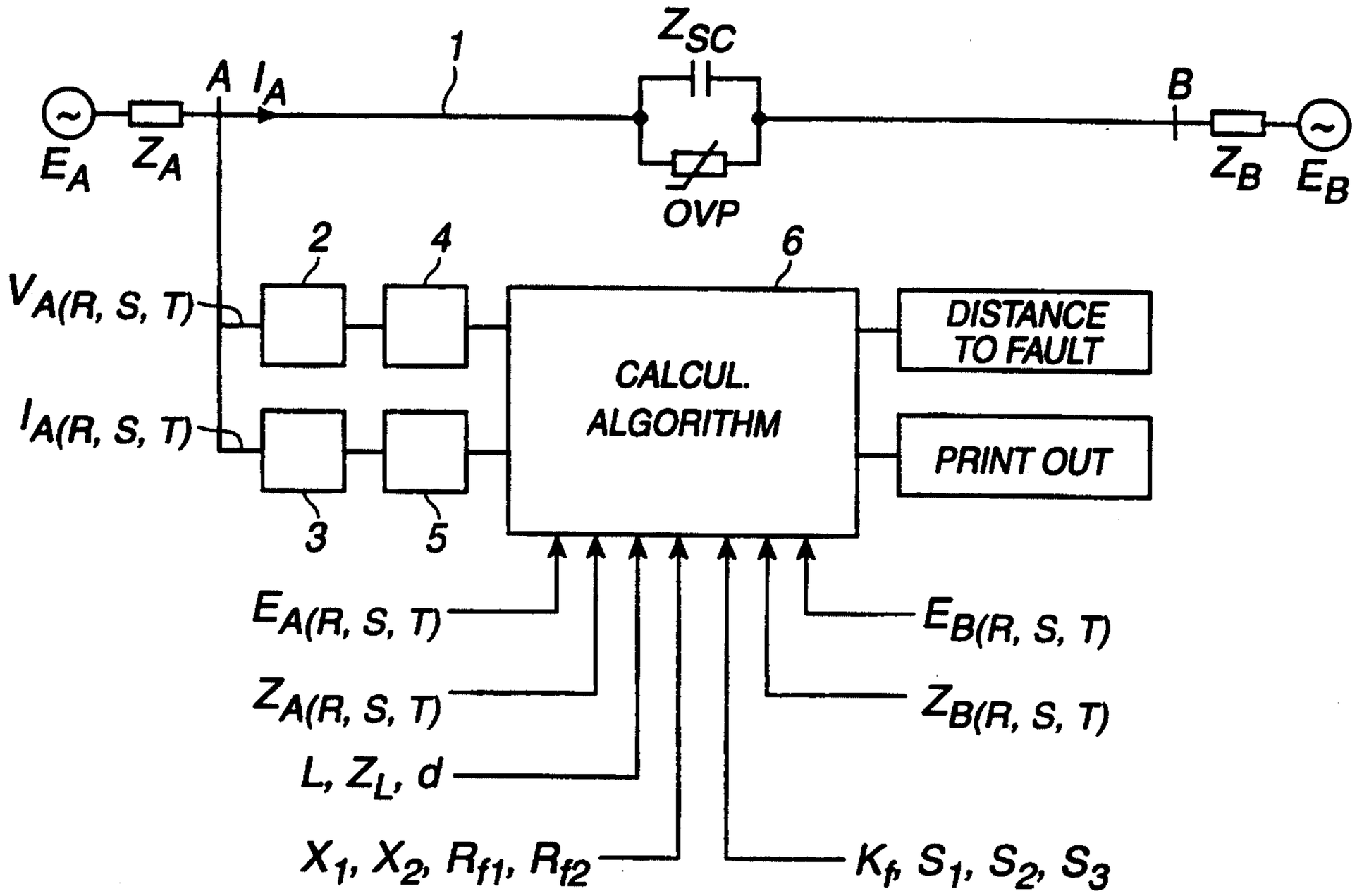
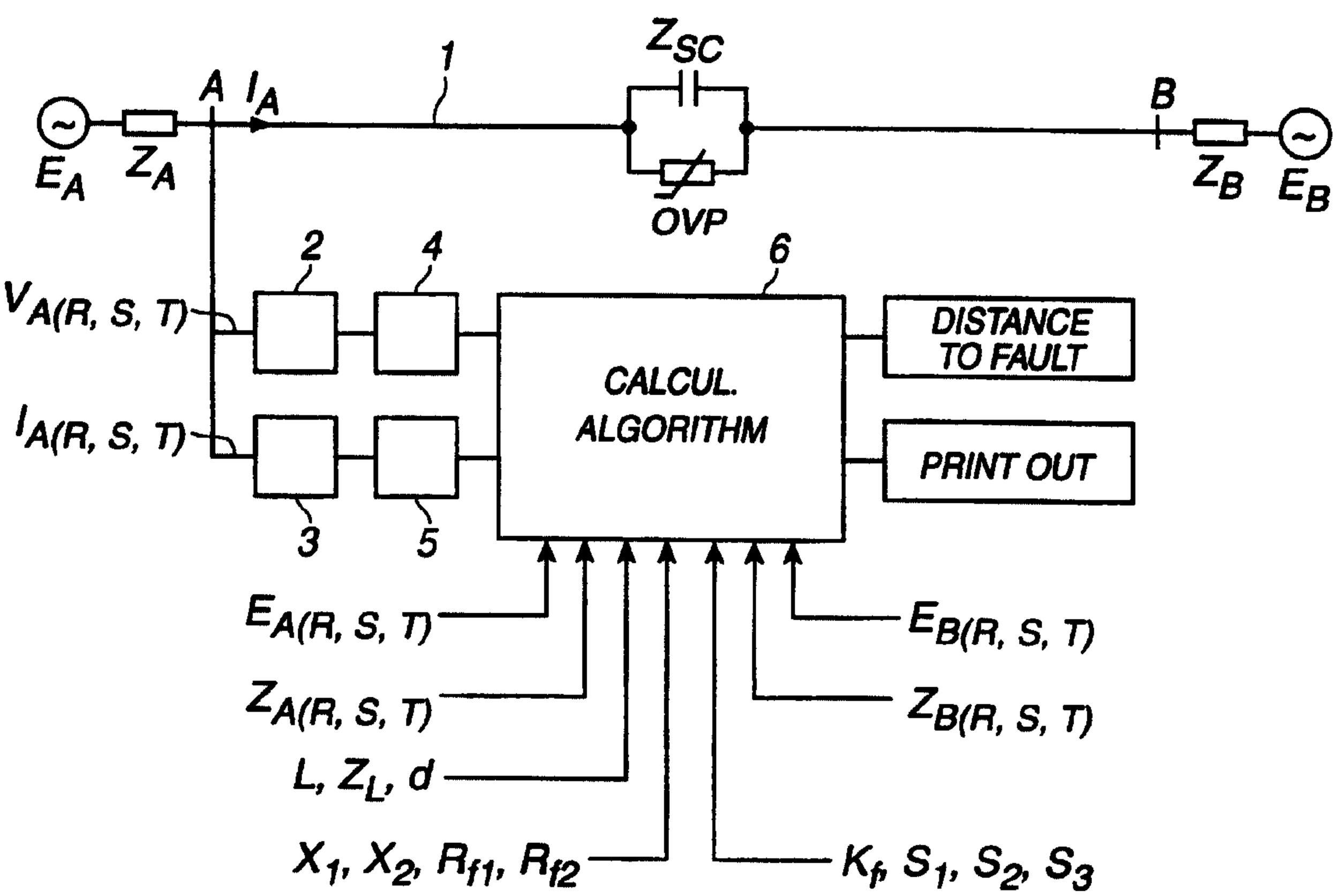

Z_{SC}
1
A I_A
B
E_A
Z_A
OVP
Z_B
E_B
2
4
6
$V_{A(R, S, T)}$
$I_{A(R, S, T)}$
CALCUL. ALGORITHM
DISTANCE TO FAULT
PRINT OUT
3
5
$E_{A(R, S, T)}$
$Z_{A(R, S, T)}$
L, Z_L, d
X_1, X_2, R_{f1}, R_{f2}
K_f, S_1, S_2, S_3
$E_{B(R, S, T)}$
$Z_{B(R, S, T)}$

Fig. 8


Z_{SC}
1
A
I_A
B
E_A
Z_A
Z_B
E_B
OVP
2
4
6
$V_{A(R, S, T)}$
$I_{A(R, S, T)}$
CALCUL. ALGORITHM
DISTANCE TO FAULT
PRINT OUT
3
5
$E_{A(R, S, T)}$
$Z_{A(R, S, T)}$
L, Z_L, d
X_1, X_2, R_{f1}, R_{f2}
$E_{B(R, S, T)}$
$Z_{B(R, S, T)}$
K_f, S_1, S_2, S_3